ARPA Network Information Center
Stanford Research Institute
Menlo Park, California 04025

NIC #14500
Packet Radio Temporary Note 26
Reference- Prior Note #15

D. B. Nixon (Collins)
12 March, 1973

Solid State RF Sources

Preface*

Packet Radio note #15 summarized the characteristics of solid state sources from a frequency range of 200 MHZ to 36 GHZ and provided an extensive bibliography on this subject. This prior note concentrated primarily on devices that may be considered typical in current products and left some questions unanswered particularly the subject of peak power capability and the related subject of thermal time constant.

Packet Radio note #26 attempts to close this gap and provide additional information on state of the art relative to power capability, efficiency, cost, and stability of these devices. The peak power capability and efficiency are critical factors affecting the terminal design since they affect range and weight of batteries required to power a portable terminal. Frequency stability may be critical since the carrier acquisition time for coherent systems is related to the frequency uncertainty. Frequency stability is also critical to the design of some spread spectrum systems now being investigated.

Material contained in this report was obtained from current literature and contact with suppliers thought to be leaders in the field.

Further investigation in this area is intended with emphasis on frequencies in region of 1-2 GHZ since this appears the most likely for a test system. Future investigations are to emphasize techniques of combining power stages for higher output; efficiency of overall systems (i.e. not just output stage) techniques for rapid turn-on and turn-off of transmitters used for packet radio transmission and transmit receive isolation requirements for packet radio systems that transmit and receive on a common frequency.

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*The preface was written by R. Hertel

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SOLID STATE RF SOURCES

1.0 INTRODUCTION

The requirements of the packet radio system for a low cost, portable user terminal dictate the use of solid state components. The most critical component, in terms of equipment power, operating frequency, weight, cost and power consumption will be the basic source of RF energy. The purpose of this note is to present the parameters of solid state sources that will have an impact on the design of the packet radio system. The commercially available solid state devices covered in this note are transistors, transferred electron devices, avalanche devices, varactor multipliers and tunnel diodes. The parameters evaluated include power, peak power limitation, voltage source requirements, efficiency, costs and frequency stability.

2.0 POWER AVAILABILITY

The output power of any particular type of device is generally a function of its operating frequency. Plots of maximum CW power available versus frequency for various types of components are given in Figures 1 through 5. These curves represent the maximum power that can be derived from individual components. Multiple components can be combined to produce increased power; however, this often introduces problems such as decreased efficiency or greater circuit complexity.

A significant factor for consideration with power sources is the mode of operation, that is, either pulse or CW. With pulse operation the power output for most devices can be many times that of CW operation. The limiting factor in pulse operation is that the length of the pulse must be less than the thermal time constant of the power device. For commercially available microwave transistors, this time is in the area of 80-130 microseconds. For the transferred

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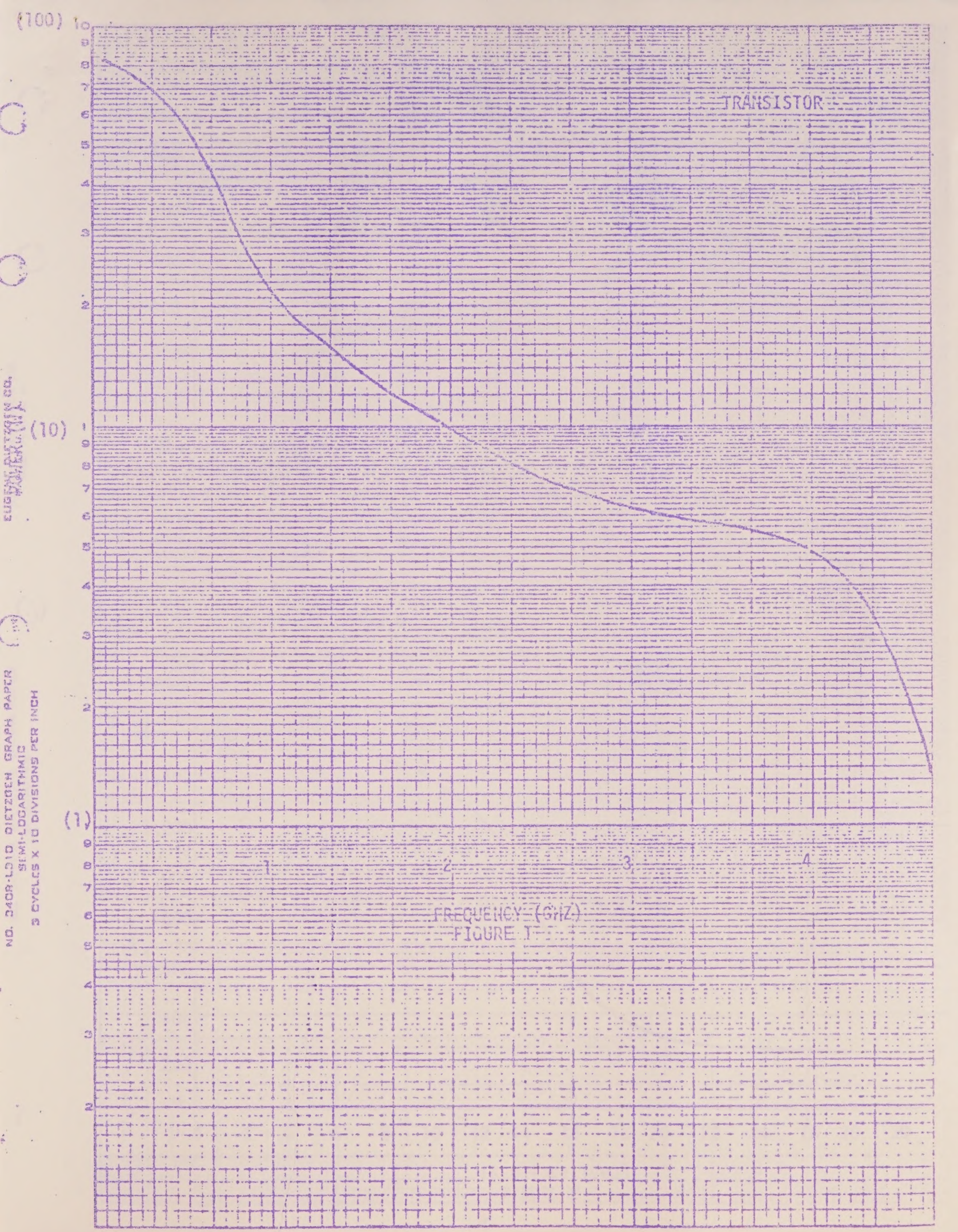
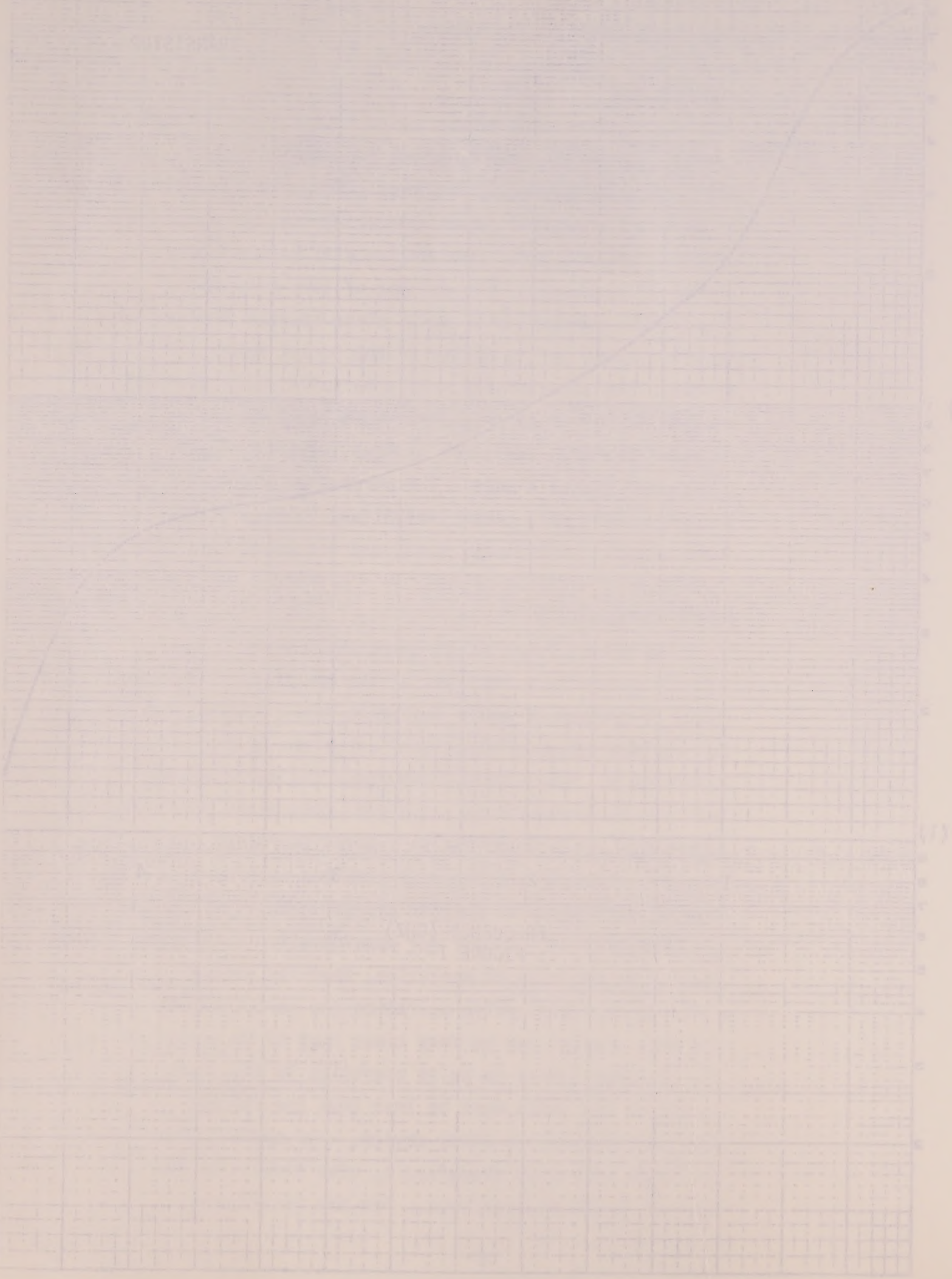


FIGURE 1

NO. 340R-LD10 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH
EUGENE DIETZGEN CO.



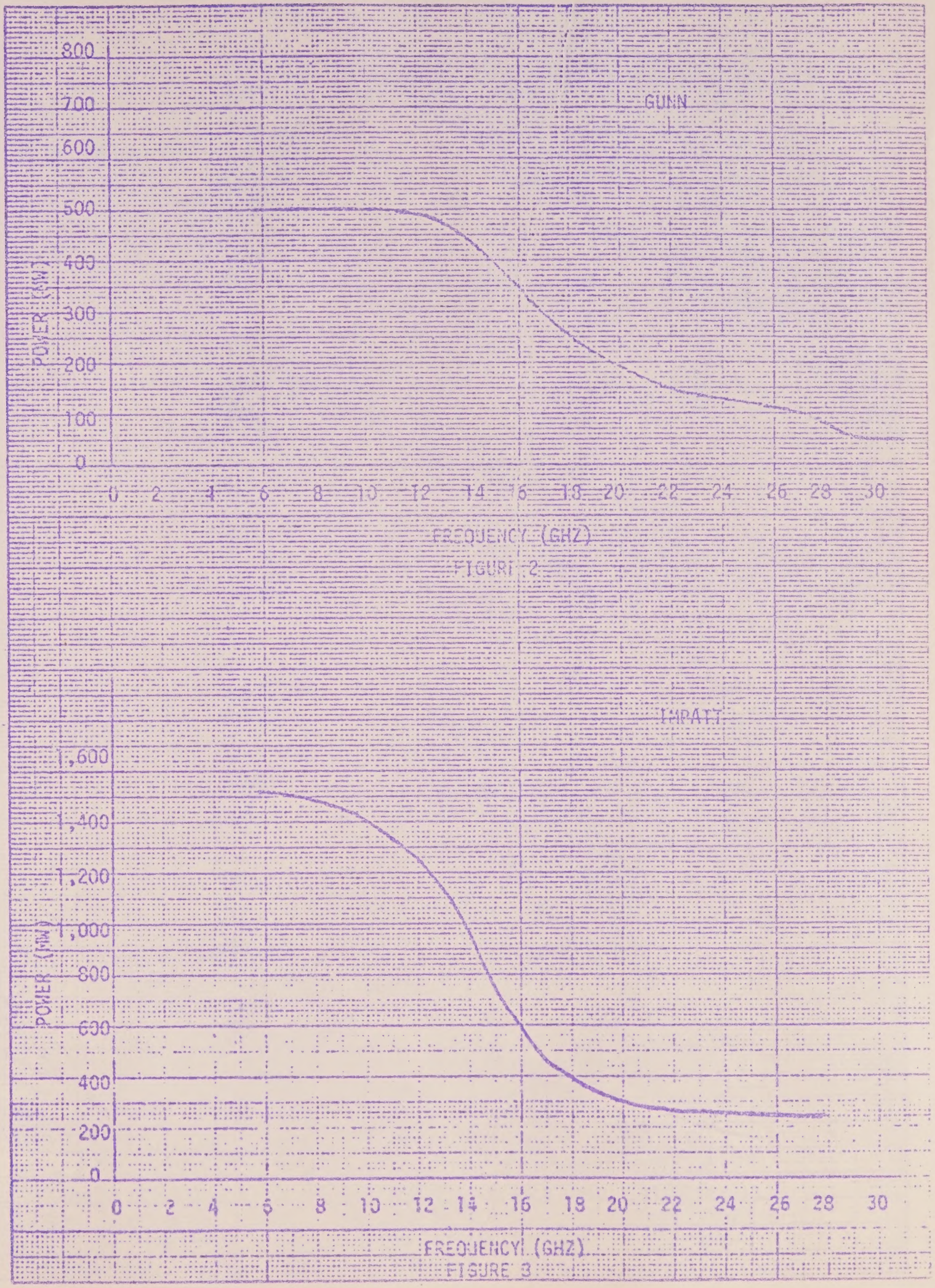


FIGURE 2

FIGURE 3

EUGENE DIETZGEN CO.
MADE IN U.S.A.
NO. 340R-M DIETZGEN GRAPH PAPER
MILLIMETER

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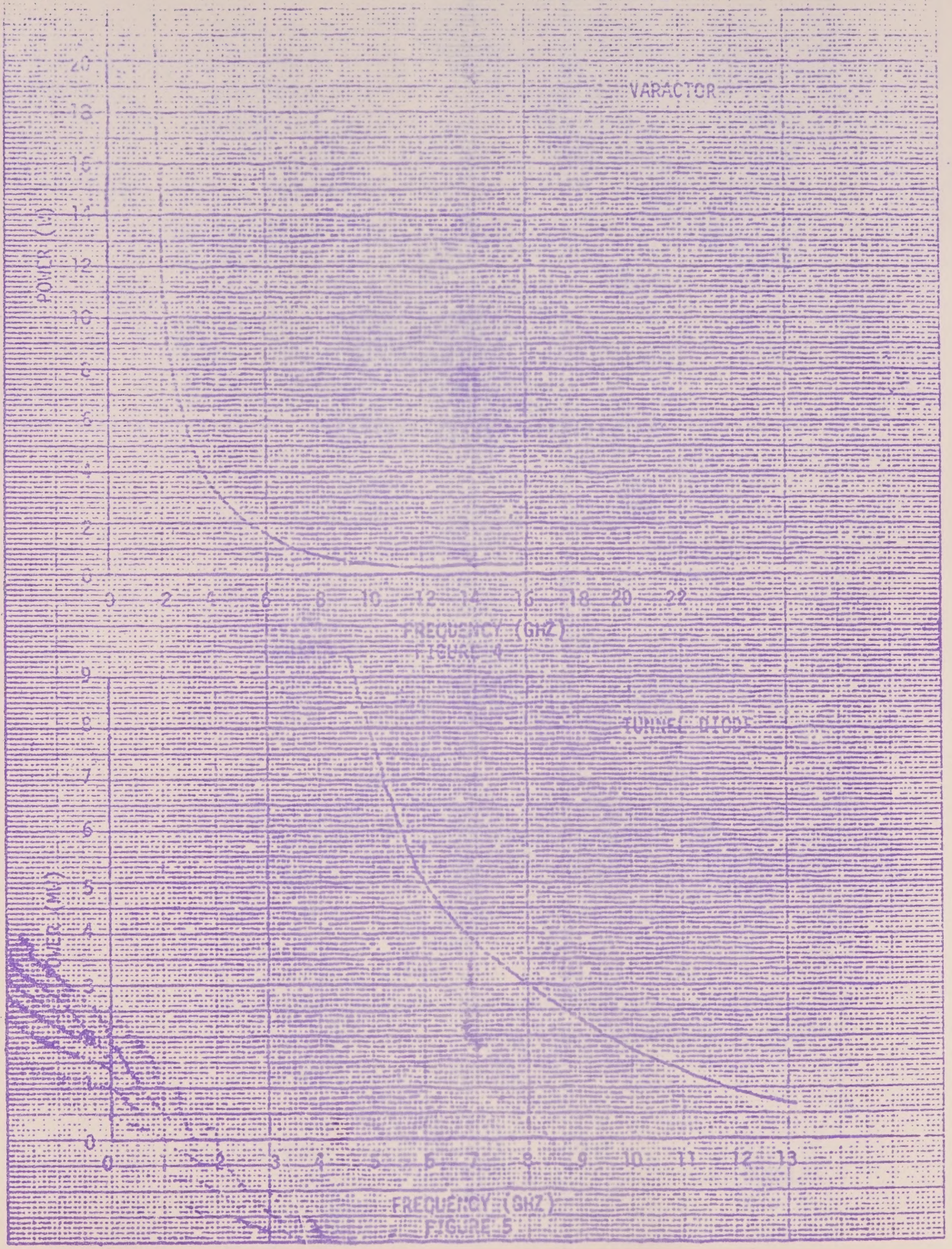
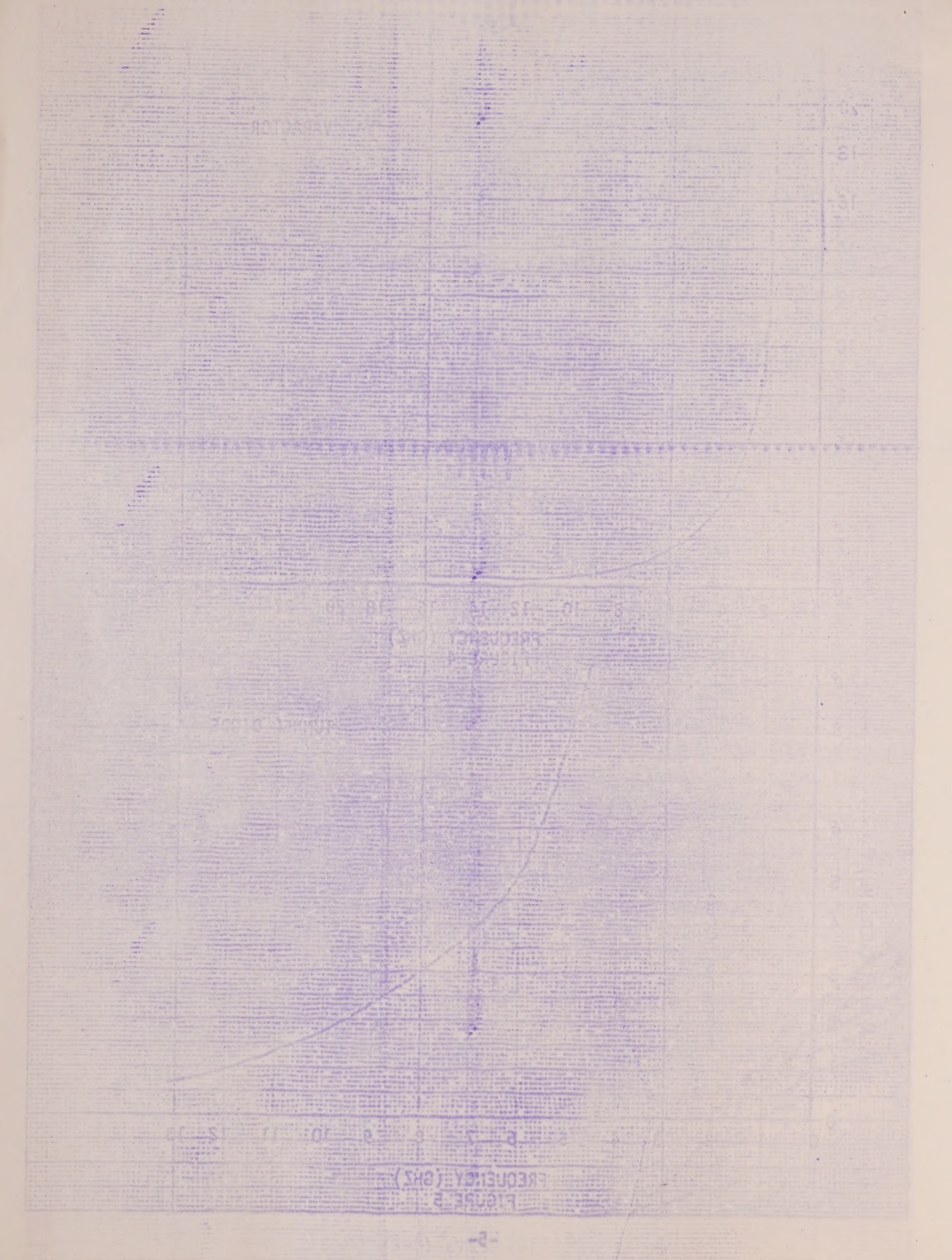


FIGURE 4

FIGURE 5



silicon, avalanche [illegible] varactor devices, the time constant is in the range of 1-5 microseconds. These short time constants result from the extremely small dimensions involved and junctions required to produce devices to work at microwave frequencies. The thermal time constant of a device is proportional to the square root of the thickness of the semiconductor chip. Since the period of a 1000 bit packet transmitted at a rate of 100 kilibits is 10 milliseconds, the CW mode of operation and its associated power limitations must be considered as the maximum power available from solid state devices in this application.

3.0 VOLTAGE SOURCE REQUIREMENTS

Since the portable user terminal must be battery powered, the operating voltage required for a power source is a critical factor. Typical operating voltages for the various types of sources are given below:

TRANSISTOR	12-28V (VHF, UHF)
	24-28V (1-4 GHZ)
GUNN	9-14V
IMPATT	80-120V (7-12 GHZ)
	50-80V (12-18 GHZ)
	30-50V (18-26 GHZ)
VARACTOR	6V (BIAS)
TUNNEL DIODE	1.3-3.0V

4.0 EFFICIENCY

Another important factor in the design of a portable user terminal is the efficiency of the power source. The typical efficiencies for various commercially available devices are given below:

TRANSISTOR	30-50%
GUNN	1-3%
IMPATT	4-10% (HIGH POWER MODELS)
VARACTOR	(SEE FIGURE 6)

associated power limitations must

as the maximum power available from solid

in this application.

portable user terminal must be battery

operating voltage required for a power

critical factor. Typical operating

types of sources are given below:

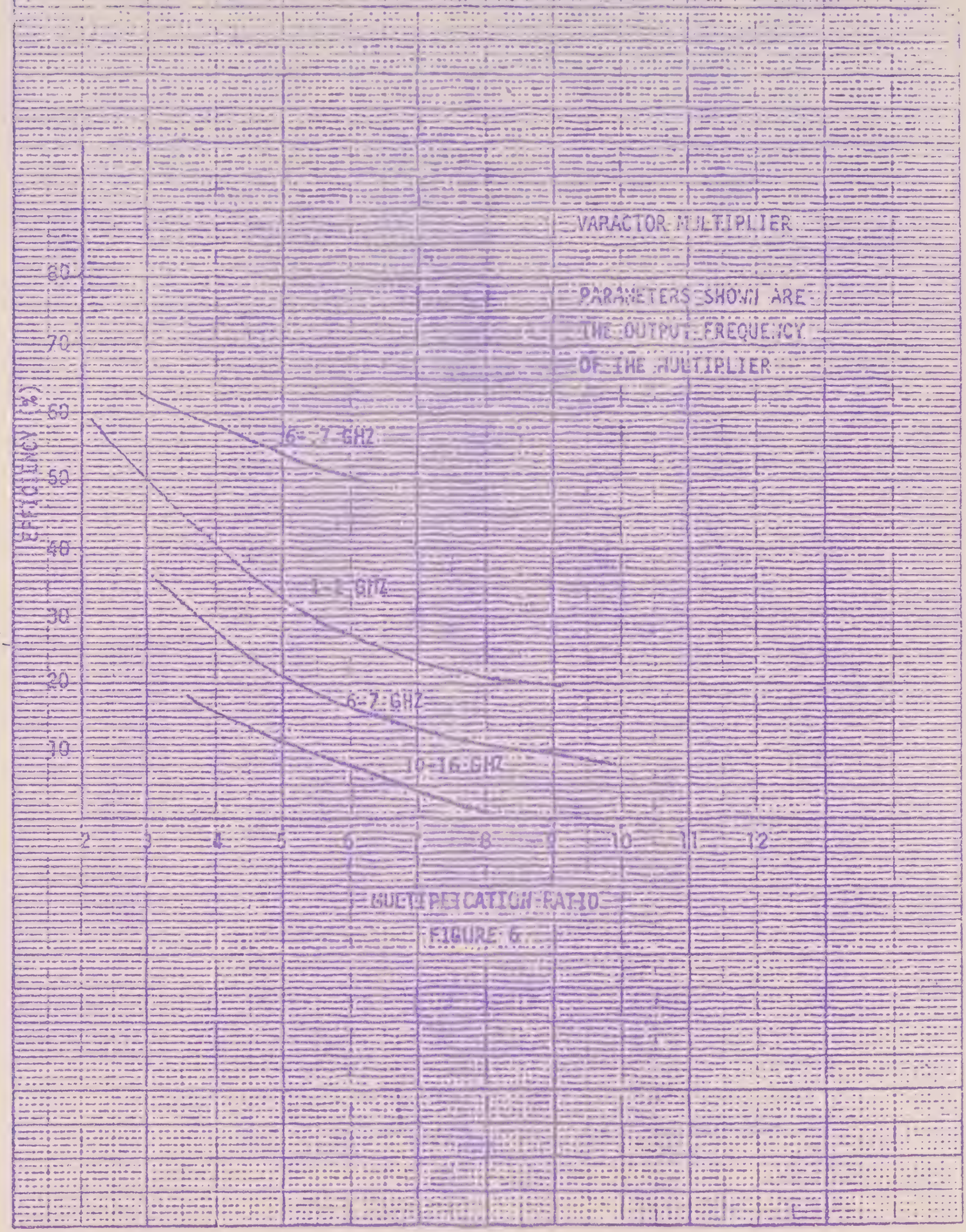
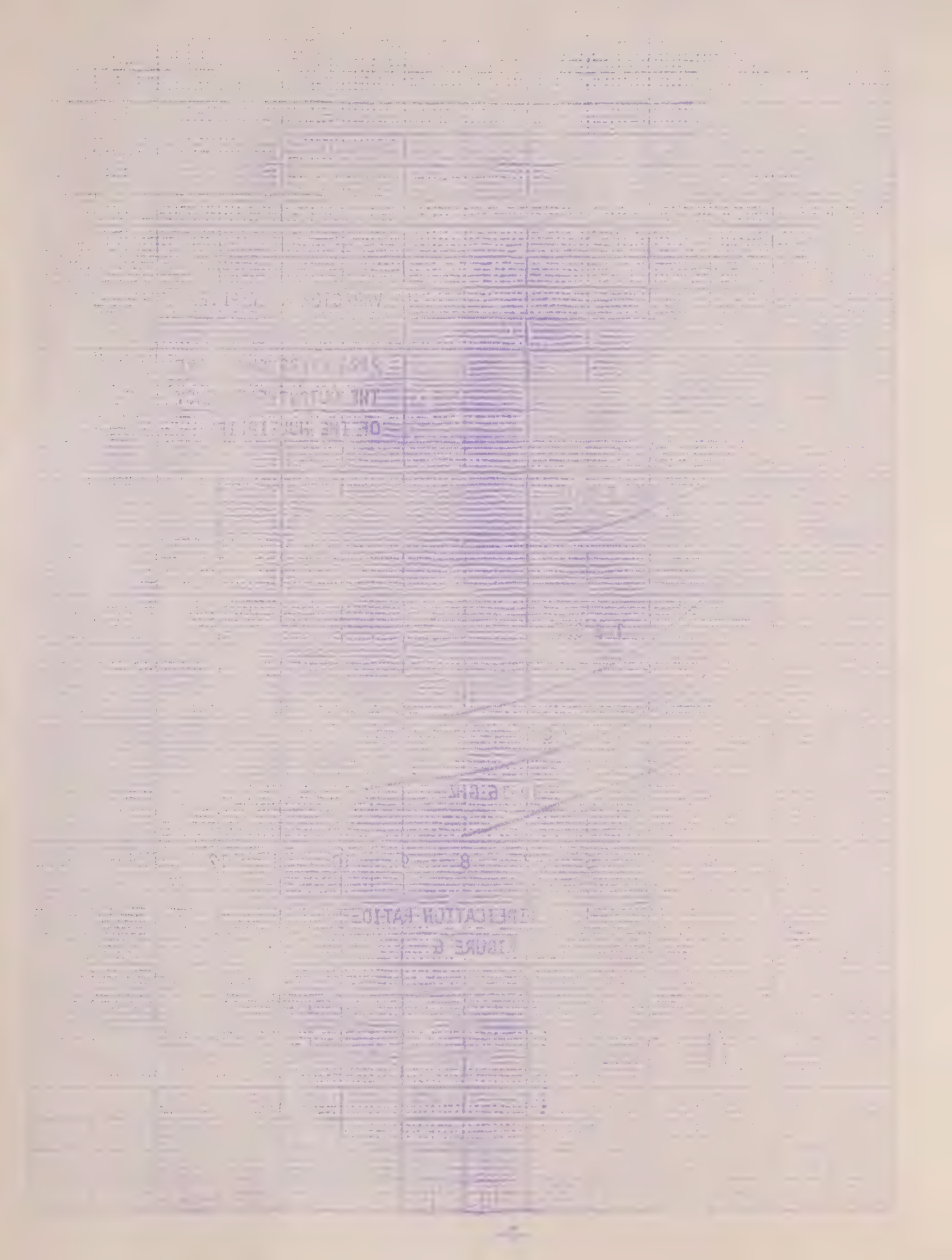


FIGURE 6

20 X 20 PER INCH



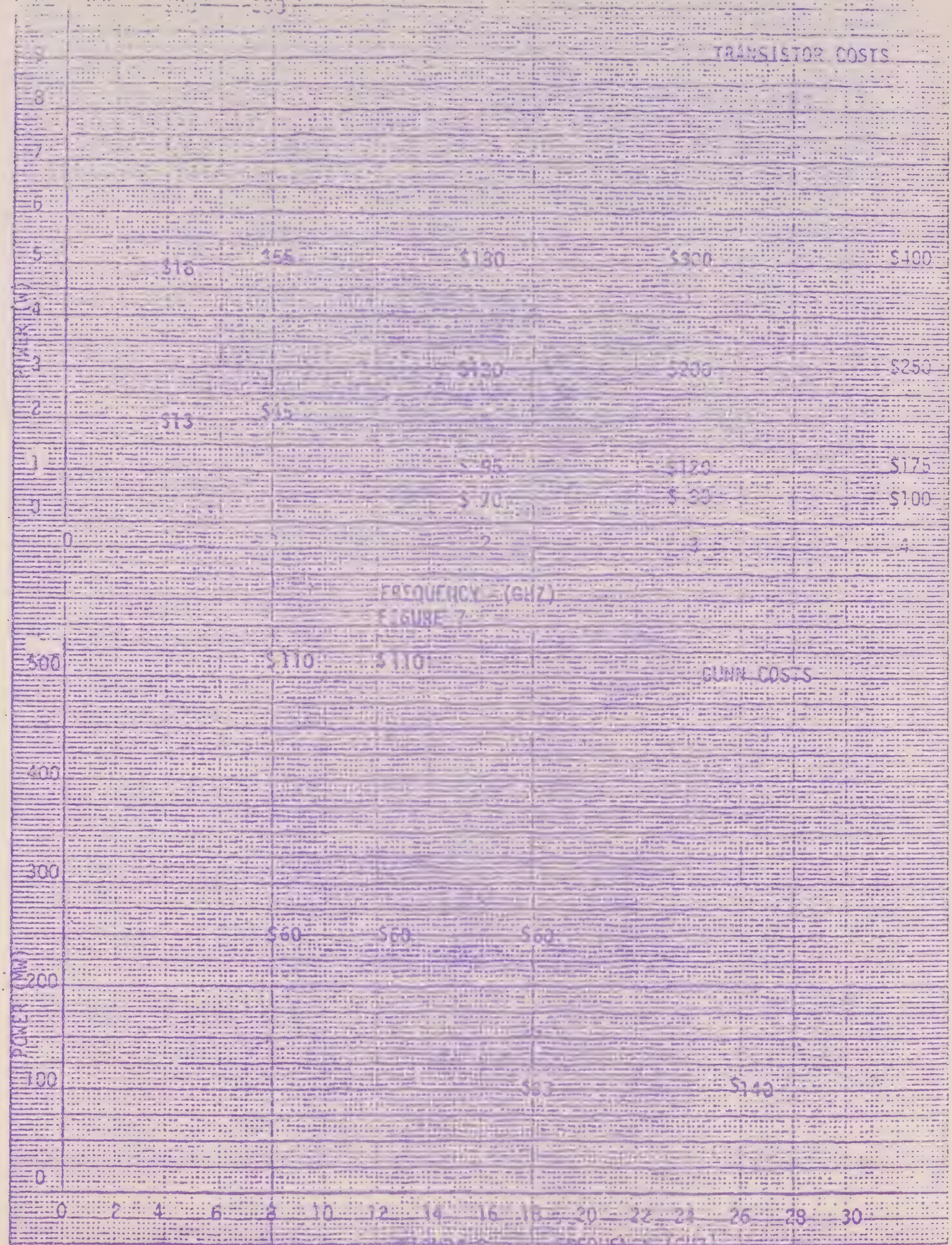
The efficiency of the varactor in Figure 6 does not include the efficiency of the driving source. When overall efficiency is considered, sources with multiple varactor stages also have quite low efficiency.

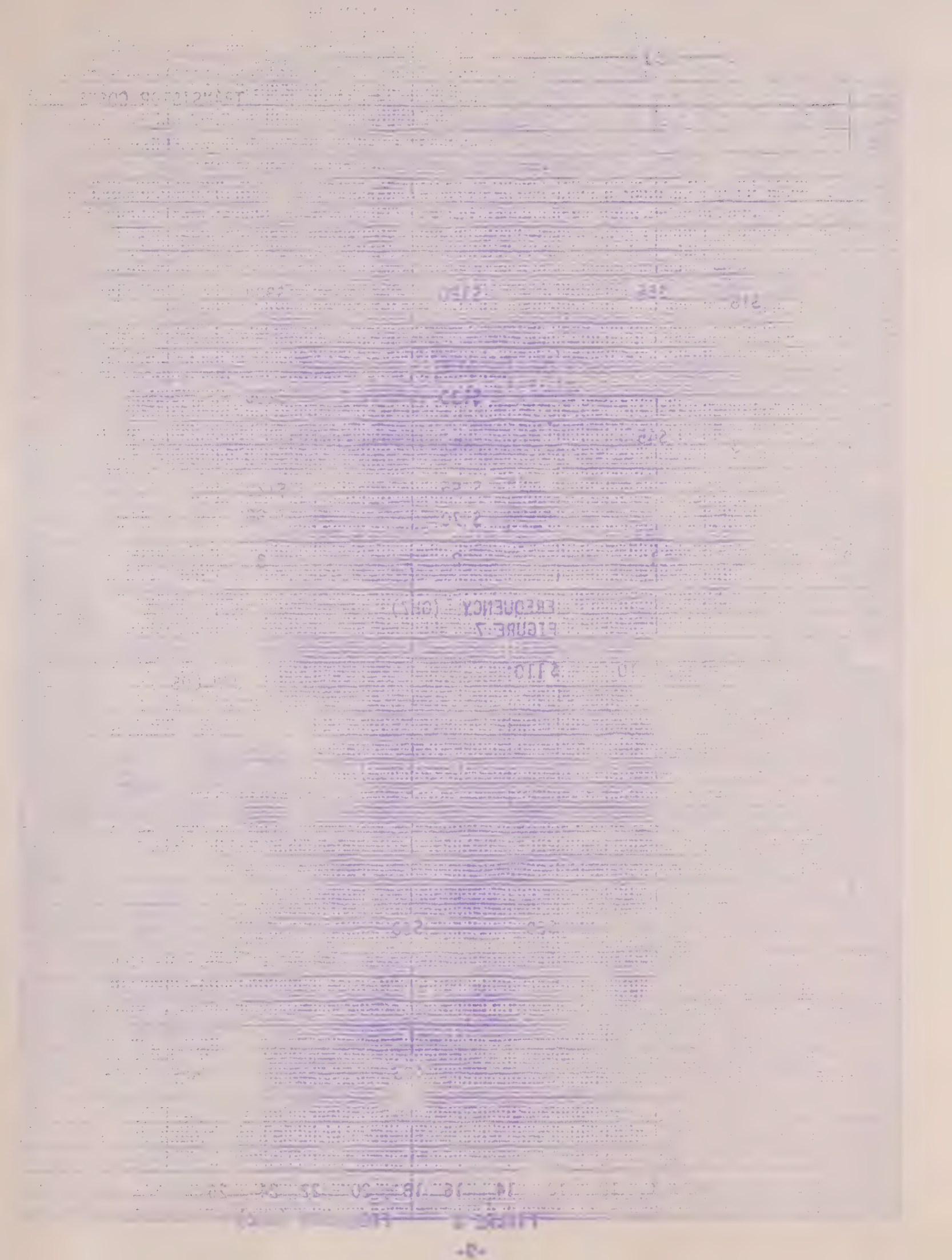
5.0 COSTS

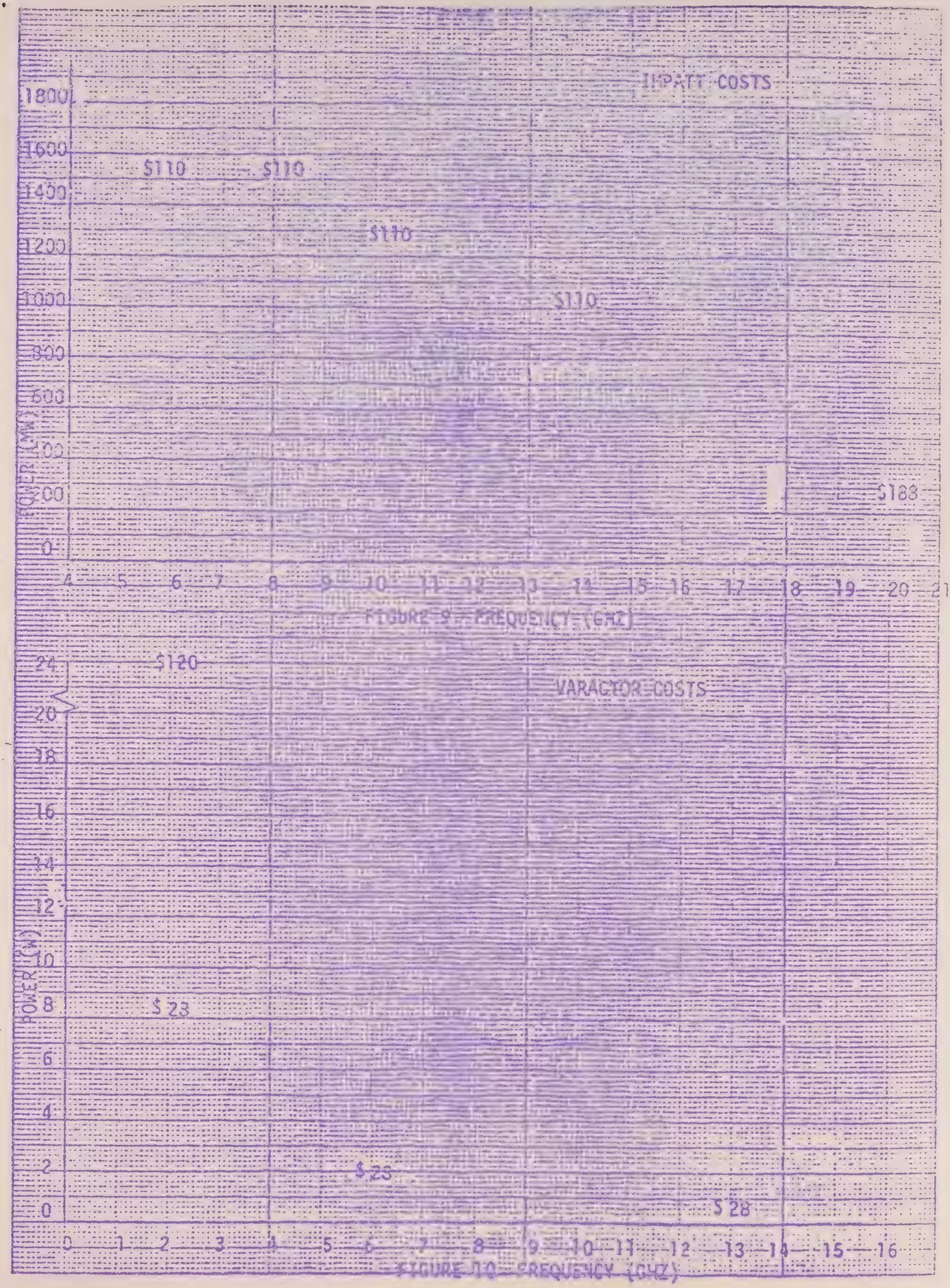
The current prices for individual power source components are given in Figures 7-10. These prices are quoted for quantities of 10-100. These figures can be used only as a rough guide since progressing technology, a highly competitive industry and large quantity purchasing can substantially change component prices. In addition, these prices represent only a portion of the total cost of the transmitter for a user terminal. Other significant cost items include resonate cavity, frequency stabilization components and modulation and control circuitry.

6.0 FREQUENCY STABILITY

As sources of microwave energy, the devices discussed in this note must be mounted in a cavity resonator. Without either an internal oven or crystal stabilization, these cavity oscillators have a frequency stability in the range of $\pm 5 \times 10^{-4}$ to $\pm 5 \times 10^{-5}$. If greater stability is required, the cavity can be phase locked to a crystal oscillator. There are currently available temperature compensated crystal oscillators, which do not have ovens, which can provide a stability of $\pm 5 \times 10^{-7}$ over a temperature range of 0° C to 50° C. These crystals operate at a frequency of 1 to 10 MHZ. However, for microwave sources it is desirable that the crystal reference operate at as high a frequency as practical to minimize the number of frequency multiplication stages needed. Use of 5th overtone 100 MHZ crystals are typical for such sources and temperature drifts of .5 ppm/°C and aging rates of ±.4 ppm per month


TRANSISTOR COSTS
$18
$15
$13
$130
$120
$95
$70
$300
$200
$400
$250
$175
$100
FREQUENCY (GHZ)
FIGURE 7
GUNN COSTS
$110
$110
$60
$60
$60
$83
$140
POWER (MW)
FREQUENCY (GHZ)
FIGURE 8




IMPATT COSTS
$110
$110
$170
$110
$188
POWER (MW)
1800
1600
1400
1200
1000
800
600
400
200
0
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
FIGURE 9 - FREQUENCY (GHZ)
$120
VARACTOR COSTS
24
22
20
18
16
14
12
10
8
6
4
2
0
$ 23
$ 23
$ 28
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
FIGURE 10 - FREQUENCY (GHZ)

after a one month period of operation are typical for such oscillators. Even greater stability ($\pm 5 \times 10^{-10}$) can be achieved with the use of a continuously operating crystal oven; however, the power drain of the oven, which would be a minimum of 2-3 watts, would impose a substantial load on the battery pack of a portable terminal and would create a "warm up" cycle that is undesirable for a packet radio system.

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BIBLIOGRAPHY

1. Hewlett Packard; 1972 Component Product Line Data.
2. Microwave Associates; December 1972 Product Line Data.
3. Microwave Semiconductor Corp; 1972 Product Line Data.
4. Hughes (Electronics Dynamics Division); 1972 Product Line Data.
5. California Eastern Laboratories, Inc.; 1972 Product Line Data.
6. TRW; 1972 Semiconductor Product Line Data.
7. Hewlett Packard, Palo Alto, California; Telephone conversation February 1973.
8. Varian Associates/Solid State East, Beverly Mass., Telephone conversation, February 1973.
9. Harry Cooke, "Microwave Transistors Part I: Power Devices", Microwaves, December 1969.
10. Company Correspondence, Texas Avionics Letter 6 February 1973.
11. Bliley Electric Company; Product Line Data.
12. McCoy Electronics Company; Product Line Data.
13. W. J. Thompson, "Aging in Quartz Crystal Resonators", Collins Internal Memorandum, 8 June 1971.
14. W. J. Thompson, "Specification revision on crystals /289 6999/7001 XXX and similar parts," Collins Internal Memorandum, 5 November 1971.
15. W. J. Thompson, "Status of the Microwave Crystal Aging Problem", Collins Internal Memorandum, 15 May 1972.
16. Malcolm McColl, "State -Of-The-Art Study of Solid-state Microwave Generators," Aerospace Corp., El Segundo, California, 31 January 1969; Distributed by Clearinghouse AD 691 234.
17. E. A. Gerber and A. A. Sykes, "State of the Art--Quartz Crystal Units and Oscillators," Proceedings of the IEEE, Vol. 54, No. 2, pp 103-115, February 1966.
18. T. Thomas, M. Ramadon, P. Hertel, "Solid State RF Sources," Packet Radio Temporary Note #15, January 19 1973.

BIBLIOGRAPHY

1. Hewlett Packard; 1972 Component Product Line Data.
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5. California Eastern Laboratories, Inc.; 1972 Product Line Data.
6. TRW; 1972 Semiconductor Product Line Data.
7. Hewlett Packard, Palo Alto, California; Telephone conversation February 1973.
8. Varian Associates/Solid State East, Beverly Mass., Telephone conversation, February 1973.
9. Harry Cooke, "Microwave Transistors Part I: Power Devices", Microwaves, December 1969.
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16. Malcolm McColl, "State -Of-The-Art Study of Solid-state Microwave Generators," Aerospace Corp., El Segundo, California. 21 January 1969; Distributed by Clearinghouse AD 697 234.
17. E. A. Gerber and A. A. Sykes, "State of the Art--Quartz Crystal Units and Oscillators," Proceedings of the IEEE, Vol. 54, No. 2, pp 103-115, February 1966.
18. T. Thomas, M. Ramadon, P. Hartel, "Solid State RF Sources," Packet Radio Temporary Note #15, January 15 1973.